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Habitat Suitability Index for Crassostrea Virginica within the Chesapeake Bay using GIS

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Abstract

The eastern oyster (*Crassostrea virginica)* resides within the Chesapeake Bay and their oyster reefs act as a habitat for many other species in the Bay. Within the Chesapeake Bay, the eastern oyster has optimal conditions that are best suited for its growth and survival, however that may be negatively affected by current changes to the Bay such as water pollution from fertilizer and animal waste, sea level rise, and ocean acidification. Therefore, it is important to find the locations within the Chesapeake Bay where optimal conditions for the eastern oyster are met because they are a critical species to the health of the Bay and the surrounding community. I created a habitat suitability index for the eastern oyster using ArcMap, a geographic information system software. The habitat suitability index incorporates data on pH, dissolved oxygen, temperature, salinity, total suspended solids, Secchi depth, and chlorophyll a. These data were obtained from monitoring stations (n = 19), provided by the Chesapeake Bay Program. Since the monitoring stations only have the water quality values for their location, spatial interpolation was done using inverse distance weighting to estimate the surrounding water quality values. This area was found by overlaying interpolated values for each variable to determine which areas of the Bay satisfy the habitat requirements for the oyster, as reported in the literature. This information would be useful to anyone seeking to grow the oyster populations or focus energy on protecting them. It was discovered that the portion of the Bay that is best suited for eastern oysters is found between Annapolis and St. Leonard. The area of the overall optimal region for eastern oyster suitability is 59770.415hectares.

Introduction

Crassostrea virginica (eastern oyster) is found in the New England/Mid-Atlantic and Southeast parts of North America (NOAA Fisheries, n.d.). This oyster is the most common type of oyster found in the Chesapeake Bay and has a large impact on the functionality of this ecosystem (Chesapeake Bay Foundation, n.d.). Ecologically, the eastern oyster is beneficial because they can improve water quality of their environment by filtering excess amount of nutrients (NOAA Fisheries, n.d.). Economically, this species is extremely valuable. *Crassostrea virginica* is an important commercial species and is widely harvested for the fishing industry (NOAA Fisheries, n.d.). Currently, the eastern oyster populations within the Chesapeake Bay are only a small portion of what they have been historically (Chesapeake Bay Foundation, n.d.). This is due to a multitude of factors including disease, pollution, and overharvesting (Chesapeake Bay Foundation, n.d.). In 1999, market sized eastern oyster populations were totaled at 600 million individuals within the Chesapeake Bay (Metcalf, 2020). However, Maryland's Oyster Stock Assessment reported only about 400 million market sized eastern oysters in June of 2020 (Metcalf, 2020). Additionally, there has also been a decrease in the number of oysters that are under one year old, with estimates of only 275 million individuals in 2020 (Metcalf, 2020). Since the eastern oyster is so influential both economically and ecologically, it is important that this species has optimal living conditions within the Chesapeake Bay. However, increasing atmospheric carbon dioxide could influence specific water characteristics that would alter the optimal conditions of the eastern oyster.

Atmospheric carbon dioxide has been steadily increasing due to human emission rates since the Industrial Revolution (Lindsey, 2021). This increase in atmospheric carbon dioxide has caused an overall increase in the greenhouse effect, as well as forcing bodies of water to absorb this excess carbon dioxide (Lindsey, 2021). This results in dramatic physical and chemical changes to these aquatic environments that directly affect the species that inhabit them (Ross & Behringer, 2019). Specifically, the absorption of carbon dioxide causes an increase in hydrogen ions which decreases the body of water's pH making it more acidic (NOAA, 2020). This decrease in pH can have a significant impact on shell building organisms (NOAA, 2020). In order to build their shells, these organisms join carbonate and calcium that is available in the water (NOAA, 2020). However, less carbonate is available for shell building due to carbonate ions combining with the excess hydrogen (NOAA, 2020). Eventually if pH gets too low, the shells of these organisms can start to disintegrate (NOAA, 2020). Therefore, if the optimal conditions for the eastern oyster are altered within the Chesapeake Bay, this could affect their survival and overall population size.

The eastern oyster has an optimal pH range of 6.75 to 8.75, with their overall pH range from 6-9 (USDA, n.d.). Therefore, if the eastern oyster is living in a pH that is outside its preferred range, it can undergo some serious effects. For instance, pH can directly alter the shell height and shape of larval oysters. Decreased pH is associated with both reduced shell height and increased shell shape deformities (Clements et al., 2020). Additionally, pH can affect eastern oyster reproduction, as well as development of oyster larvae. When pH is decreased, gametogenesis can delay significantly and in serious cases can inhibit the process entirely (Boulais et al., 2017). Similar findings were reported for fertilization, this was attributed to the fact that more acidic conditions become stressful for the eastern oyster, and this causes them to allocate more energy into maintenance of the organism rather than putting energy towards reproduction and growth (Boulais et al., 2017). However, it is also important to consider that researchers believe juvenile eastern oysters could be acclimating to the changing pH. For example, cycling pH was associated with increased growth rate in juvenile eastern oysters (Keppel et al., 2016).

Variables including dissolved oxygen, salinity, and temperature can also have direct effects on the eastern oyster. Decreased dissolved oxygen levels are associated with issues such as higher susceptibility to disease and reduced growth (NCCOS, 2014). Specifically, within the Chesapeake Bay, declining oxygen levels are weakening the eastern oyster's ability to fight Dermo, which is a disease that attacks the blood cells of oysters and can cause growth issues as well as large mortality events (NCCOS, 2014). Eastern oysters appear to be adaptable to short-term variability in temperature and salinity, but long-term exposure to increased salinity and temperature will result in increased mortality of eastern oysters (Laakkonen, 2014). Additionally, increased salinity and temperature reduce the oyster's ability to feed, resulting in decreased growth rates (Lowe et al., 2017).

Additional variables that are useful in understanding water quality for eastern oysters include total suspended solids, Secchi depth, and chlorophyll a level. Secchi depth is used to measure turbidity of water by lowering the Secchi disk into a body of water and noting the depth at which you can no longer see it (United States Environmental Protection Agency, 2006). Total suspended solids and chlorophyll a levels directly relate to the turbidity of the body of water. Increased total suspended solids within a body of water can have some adverse effects. For example, higher levels of suspended solids can carry toxins into the aquatic ecosystem as well as increase water temperatures (Environmental Protection Agency, 2012). Chlorophyll a levels are a measure of how much algal growth is happening in a waterbody (Environmental Protection Agency, 2021). This type of information is useful due to chlorophyll a being the primary chlorophyll in the cyanobacteria and algae that oysters consume (Perrino & Ruez, 2019). Therefore, moderate levels of chlorophyll a are better for oyster consumption, however if levels are too high this could be associated with excess nutrients within the waterbody that cause algal blooms (Environmental Protection Agency, 2021).

In order to predict where optimal conditions for the eastern oyster are within the Chesapeake Bay; a habitat suitability index was created using ArcGIS. Within the habitat suitability index, layers were created for each variable that could affect eastern oyster survival. These variables include pH, dissolved oxygen, temperature, salinity, total suspended solids, Secchi depth, and chlorophyll a. Data for these variables are tracked using monitoring stations within the Chesapeake Bay that were provided by the Chesapeake Bay Program. Ultimately, this habitat suitability index for the eastern oyster could be beneficial in a couple of ways. For example, fishing industries could utilize it for harvesting purposes and federal agencies like NOAA Fisheries could use it for the creation of new oyster reefs. Additionally, this information could be used to identify areas that should be protected if eastern oyster populations decrease dramatically.

Methods

To create a habitat suitability index for the eastern oyster in the northern part of the Chesapeake Bay, I used the most recent values for the variables being considered. To get these values, I used a water quality database created by the Chesapeake Bay Program. The variables I examined consisted of pH, dissolved oxygen, temperature, total suspended solids, Secchi depth, chlorophyll a, and salinity. The database gets its information from active monitoring stations that are located at different positions within northern parts of the Chesapeake Bay (Chesapeake Bay Program, 2022). In total I used data from 19 monitoring stations, 18 in the middle of the northern part of the Bay and 1 in the Susquehanna River near Havre De Grace (Figure 1). For the purpose of this habitat suitability index, I only used the monitoring stations in the main stem of the Bay. From there, I took the average value of each variable from 2019-2021 for each monitoring station. The averages for each variable were used from 2019-2021 because it gives insight into the trends of these variables since they vary seasonally, instead of the immediate values that are occurring.

I then placed these values into an excel file along with the latitude and longitude for each monitoring station, which I then converted into a CSV file. Next, I uploaded the CSV file into ArcMap and used the WGS 1984 datum for this geographic data. I then converted the CSV to a shapefile in ArcMap. There was already a pre-existing layer consisting of a polygon of the Chesapeake Bay from the Chesapeake Bay Program Geoplatform that I used as an outline of the bay (Chesapeake Bay Program, 2020). However, in order to do the spatial interpolation needed for the project, I needed to turn the polygon into a polyline. A polyline was needed to provide the borders for the areal extent of the spatial interpolation.

In order to convert the polygon into a polyline, I first converted the polygon to raster and then from raster to polyline. Following the conversion to a polyline, I then cut the polyline to only include the northern portion of the bay that contained the monitoring stations. In order to perform interpolation on the existing layer with the data, I converted WGS 1984 into a projected coordinate system, such as UTM. This conversion is needed because UTM is based on WGS 1984 but utilizes linear units instead of degrees. Therefore, when distance and area are being calculated, the measurements are more meaningful. I then projected the layer with all variable data for the monitoring stations into UTM zone 18, which is the zone appropriate for the Chesapeake Bay. Next, I utilized inverse distance weighted (IDW) interpolation for each variable. Within this process, a new layer was created for each variable and points that do not have data associated with them were mathematically assigned values based off their proximity to the known data points. I used this type of spatial interpolation due to the limited amount of area that the monitoring stations covered.

Next in order to find areas of optimal overlap within the IDW layers for each variable, I reclassified each layer. The reclassification process classifies anything that is in the variables optimal range with a value of 1 and anything outside the optimal range with a value of 0. Therefore, the optimal ranges for all variables should be considered. In terms of good water quality for the Chesapeake Bay, the optimal value for Secchi depth is any value greater than or equal to .970 meters (Maryland Department of Natural Resources, 2019). The optimal values for chlorophyll a in the Chesapeake Bay consist of anything less than or equal to 15 µg/L (Maryland Department of Natural Resources, 2019). The optimal values for total suspended solids within the Chesapeake Bay consist of anything less than or equal to 15 mg/L (Maryland Department of Natural Resources, 2019). The optimal range of dissolved oxygen for the eastern oyster is greater than or equal to 5 mg/L (Chesapeake Bay Program, n.d.). The optimal range of salinity for the eastern oyster is 5-40 ppt (Bradley, 2018). The optimal temperature range for the eastern oysters is 20°C-32.5°C (Bradley, 2018).

After the reclassification process, I converted the raster to polygons so that overlay of the variables is easier. In order to build the overlay, I first needed to perform a layer selection and select by attribute. I then selected for the grid codes that were equal to 1 for all variables. This then allowed for me to overlay and look at the independent relationships among the variables by intersecting the polygons. The intersection of the polygons resulted in a new polygon where all the variables are equal to 1. The new polygon consisted of the area with optimal conditions of the variables considered for the eastern oyster.

Results

Each variable I analyzed had its own independent area in the northern part of the Bay in which its optimal values were located for the eastern oyster (Figures 2-7). The optimal area of the Bay for Secchi depth according to my reclassification layer is all the area that is below Annapolis, while the parts of the Bay located above Annapolis are inadequate (Figure 2). Specifically, the optimal area totals approximately 109,457.248 hectares. Almost the entirety of the northern part of the Bay was optimal for chlorophyll a levels except for the regions immediately surrounding specific monitoring stations (Figure 3). Specifically, the optimal area totals approximately 205,252.870 hectares. The optimal regions for total suspended solids include all of the area under Rock Hall, while the levels above Rock Hall are inadequate (Figure 4). The optimal area totals approximately 170,695.322 hectares for total suspended solids. A majority of the northern part of the Bay is optimal for dissolved oxygen levels, except for the water closest to Kent Island/Stevensville, as well as the water immediately surrounding certain monitoring stations (Figure 5). The optimal area for dissolved oxygen is approximately 191,633.086 hectares. In terms of salinity, all regions of the northern part of the Bay were optimal values, except for the very tip of the Bay, which consisted of all the water area above Chestertown (Figure 6). The optimal area for salinity is approximately 189,934.116 hectares. Temperature appeared to only be optimal in the middle section of the northern part of the Bay (Figure 7). More specifically, the area of water in between the Chesapeake Bay Bridge and St. Leonard. However, the surrounding regions above and below were not optimal for temperature. The optimal area for temperature is approximately 98,608.067 hectares. Finally, the entirety of the northern part of the Bay contained pH values that were optimal for eastern oyster survival. Therefore, pH did not have to be included when overlaying the optimal regions.

When these optimal regions for Secchi depth, chlorophyll a, total suspended solids, salinity, dissolved oxygen, and temperature were overlayed, it was discovered that the portion of the Bay that is best suited for eastern oysters is found between Annapolis and St. Leonard (Figure 8). The area of the overall optimal region for eastern oyster suitability is 59,770.415 hectares. This is 28.5% of the total area of the Chesapeake Bay analyzed.

Figures

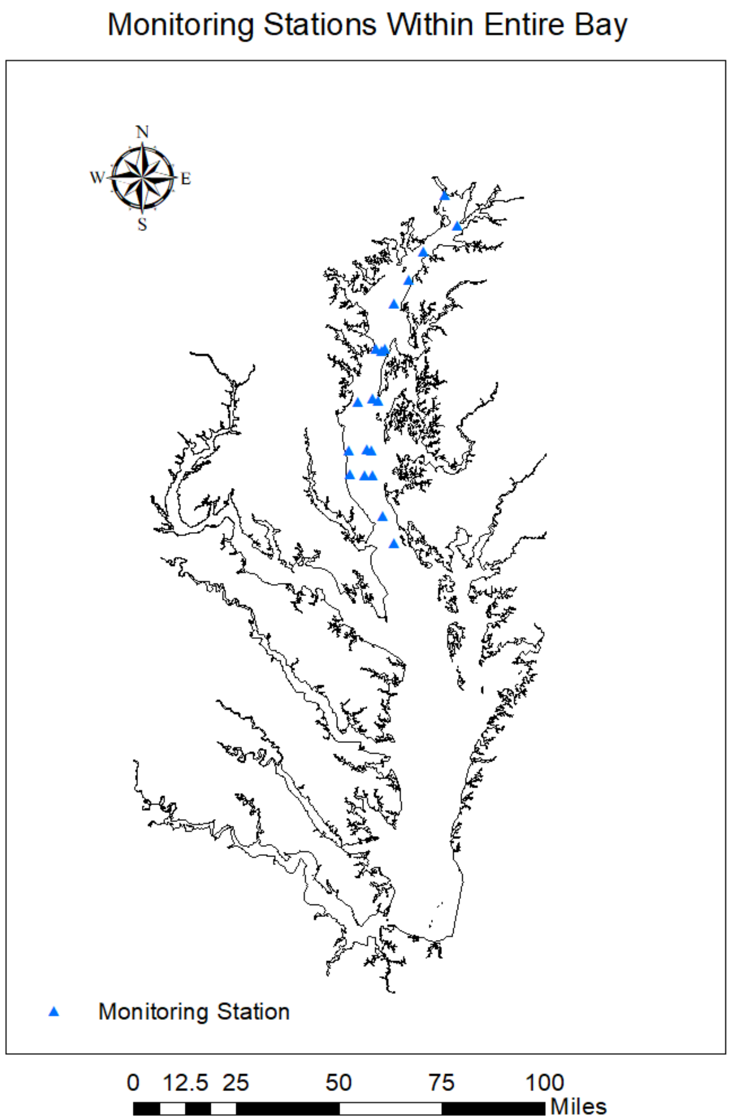

Figure 1. Map of the Chesapeake Bay showing the points where Chesapeake Bay Program monitoring stations are located.

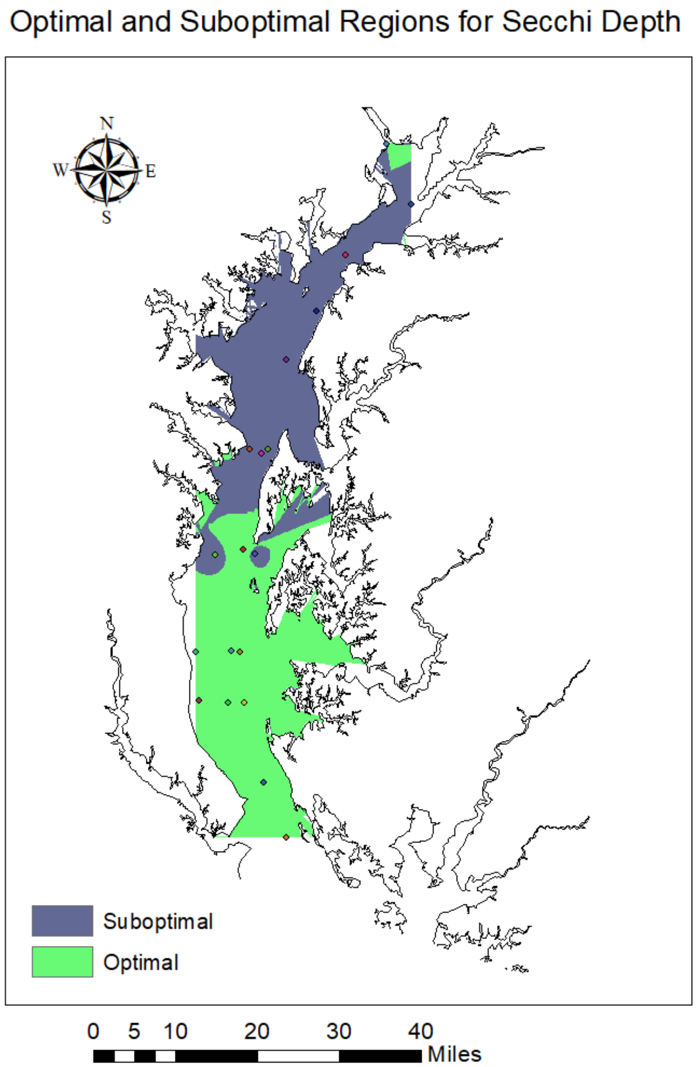

Figure 2. Map showing the optimal (green) and suboptimal (grey) regions of the northern part of the Chesapeake Bay for Secchi depth. The optimal range for Secchi depth consists of any value greater than or equal to 0.970 meters.

Optimal and Suboptimal Regions for Chlorophyll a

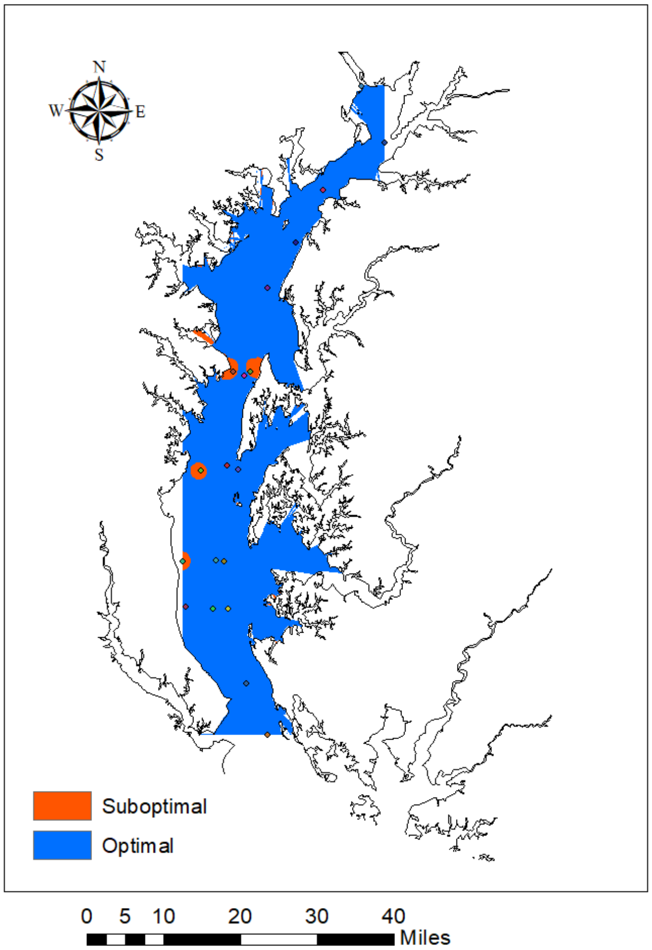

Figure 3. Map showing the optimal (blue) and suboptimal (red) regions of the northern part of the Chesapeake Bay for chlorophyll a. The optimal range for chlorophyll a consists of any value less than or equal to 15 µg/L.

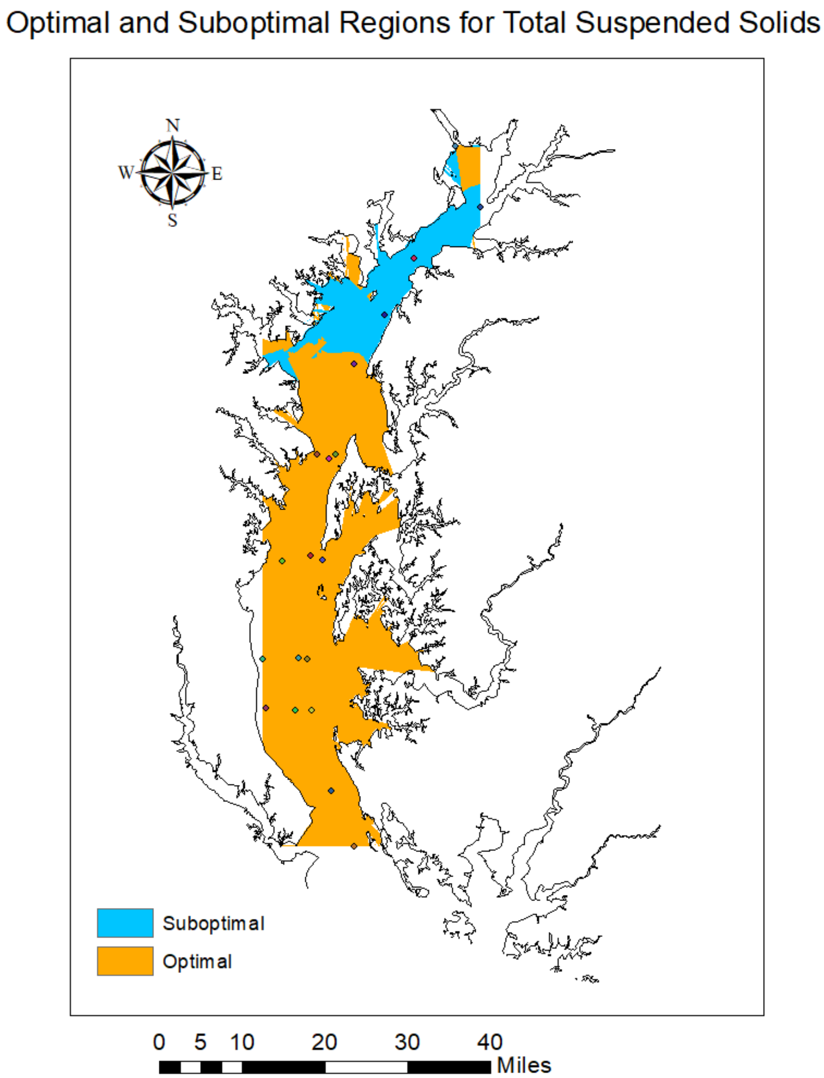

Figure 4. Map showing the optimal (orange) and suboptimal (blue) regions of the northern part of the Chesapeake Bay for total suspended solids. The optimal range for total suspended solids consists of any value less than or equal to 15 mg/L.

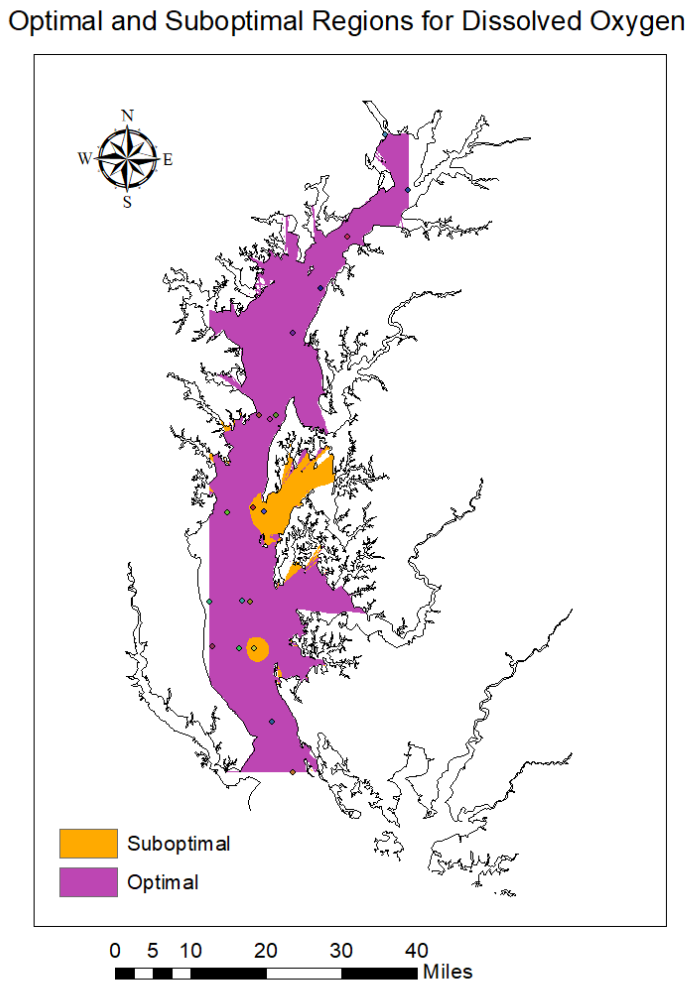

Figure 5. Map showing the optimal (magenta) and suboptimal (orange) regions of the northern part of the Chesapeake Bay for dissolved oxygen. The optimal range for dissolved oxygen consists of any value greater than or equal to 5 mg/L.

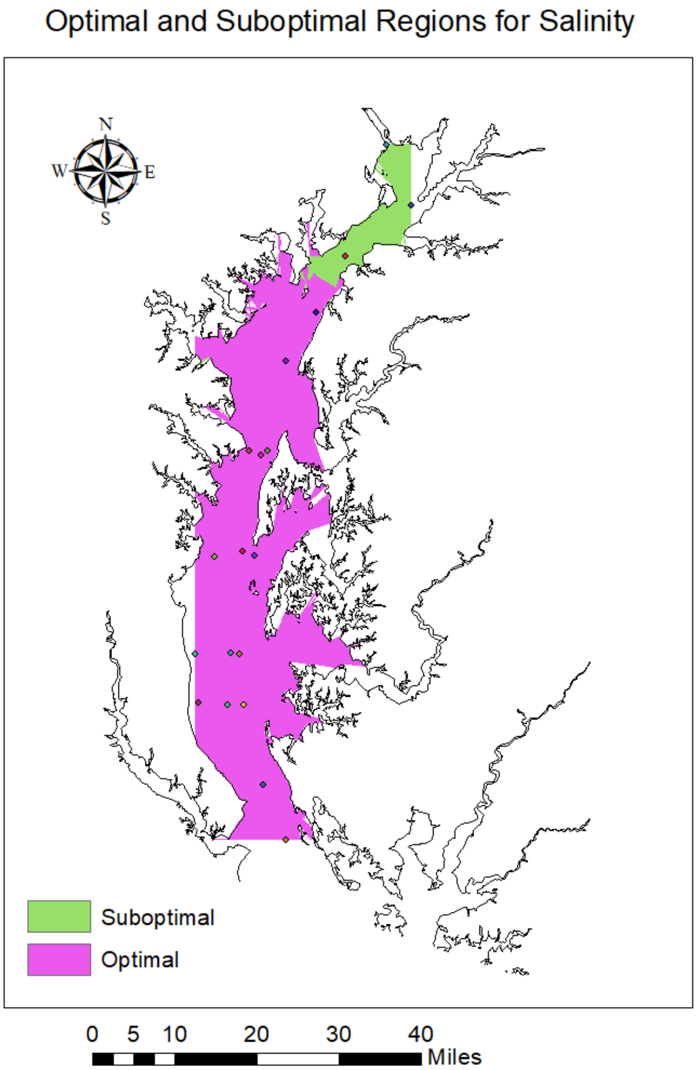

Figure 6. Map showing the optimal (pink) and suboptimal (green) regions of the northern part of the Chesapeake Bay for salinity. The optimal range for salinity consists of any value between 5-40 ppt.

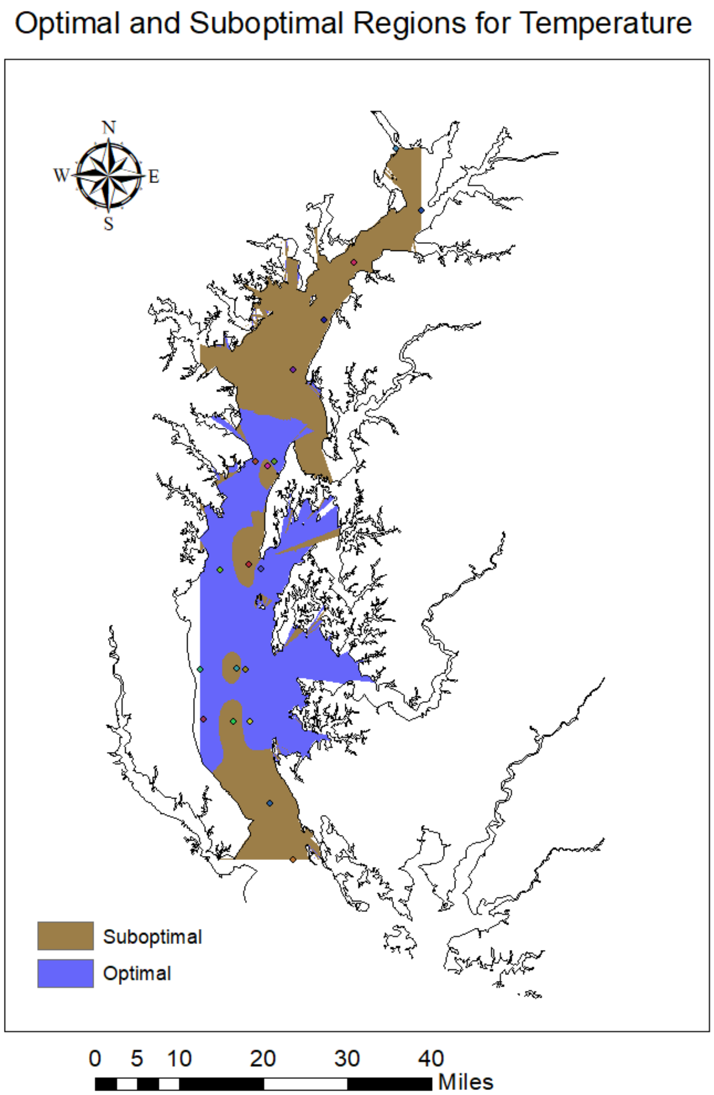

Figure 7. Map showing the optimal (purple) and suboptimal (brown) regions of the northern part of the Chesapeake Bay for temperature. The optimal range for temperature consists of any value between 20°C-32.5°C.

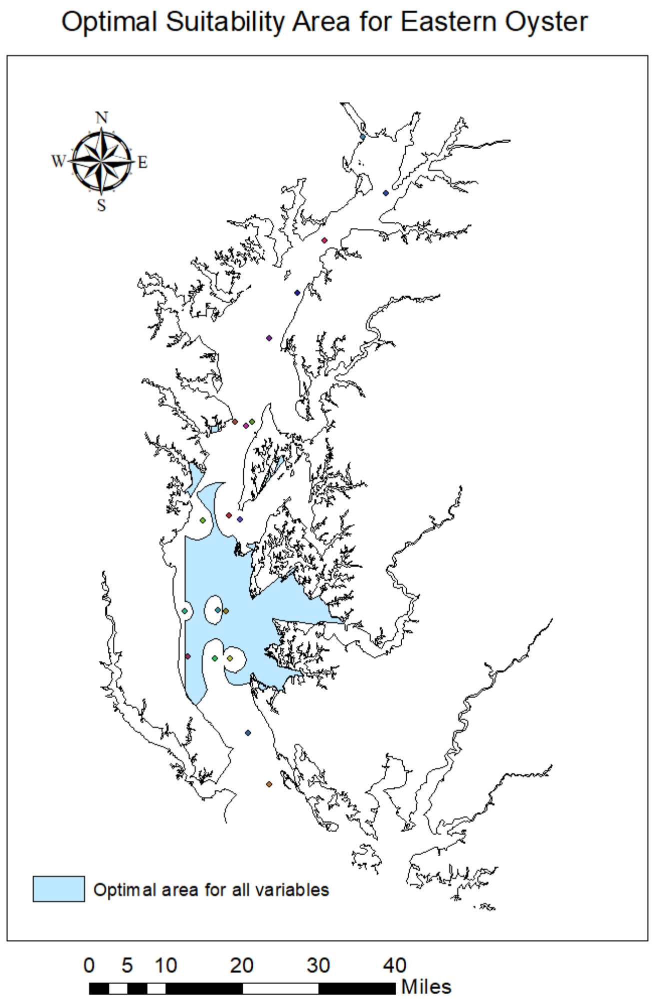

Figure 8. Map showing the overlay of optimal regions (blue) of the northern part of the Chesapeake Bay for Secchi depth, total suspended solids, chlorophyll a, dissolved oxygen, salinity, and temperature.

Discussion

Currently, there appears to be a lot of overlap between the coastal regions I indicated as optimal for eastern oyster growth and historical oyster bar locations (Maryland Department of Natural Resources, 2019). Some additional uses of the area that I identified as optimal within the Bay include both recreational and commercial fishing (Maryland Department of Natural Resources, n.d.) Knowing where these optimal locations are may be beneficial both in terms of economics and conservation. Economically, these locations could help to support the local fisheries and watermen. Additionally, knowing these locations could assist in conservation strategies if eastern oyster populations continue to decline.

By identifying the optimal spatial extent of these variables, it could shed light onto where future oyster reefs should be put in. Currently, the Chesapeake Bay Program is implementing and promoting to re-establish oyster reefs in Chesapeake tributaries (NOAA Fisheries, n.d.). Specifically, five creek and river locations in Maryland and five in Virginia (NOAA Fisheries, n.d.). These locations were chosen by the Chesapeake Bay program due to the tributaries being at varying progress levels in terms of tributary restoration plans, creating and seeding oyster reefs, and assessing restored oyster reefs (Chesapeake Progress, 2020).

However, these locations do not align with the areas that I have identified within the habitat suitability index. A similar research approach was done for the eastern oyster within the Chesapeake Bay by Battista (1999). There is little agreement between Battista's habitat suitability index and my results. Battista (1999) finds the most optimal regions of the Bay to be in the more southern regions of the Bay. However, these locations were not included within my habitat suitability index due to lack of monitoring stations in those regions. Additionally, points of divergence could have been rooted from the use of different variables to build the habitat suitability index. Battista (1999) variables included salinity, temperature, bathymetry, substrate, dissolved oxygen, chlorophyll *a*, disease intensity, and total suspended solids. There is some overlap between Battista's variables and the ones I used, but ultimately the differences could cause discrepancies in optimal locations within the Bay. Another possible point of divergence could have been caused by changing conditions since the publication of Battista (1999). Specifically, the characteristics of the Chesapeake Bay have changed from 1999 to now, which could have caused shifts in the optimal Bay areas. A final point of divergence is the time scale for the data collection of the Bay variables. Within Battista's paper, the variables were analyzed seasonally and had separate indices for each season. These indices did appear to vary seasonally. Specifically, there is more suitable area for eastern oysters in the fall and spring seasons compared to the winter and summer. This could cause differentiation in optimal area locations when compared to my index that was built on a three-year average of the variables.

An additional similar research approach was done for the eastern oyster within the Chesapeake Bay by Bradley (2018). There appears to be some agreement between Bradley's habitat classification and the optimal region from my results. Bradley (2018) found the most optimal areas of the Bay for summer and fall spawning to be near the regions that I identified, as well as in southern regions of the Bay. The reasons for this alignment could be attributed with similar variables being used. For instance, Bradley (2018) included values for temperature, salinity, pH, and dissolved oxygen. Bradley (2018) used a similar data collection method to me in terms of averaging the values for these variables across a longer time period, however they used a 5-year average.

The results of my habitat suitability index conflict with the original concerns that sparked this research. pH appears to be optimal across the entirety of the northern part of the Bay, which was not expected. However, this could be due to limitations within the research, as well as adaptations by the oysters. The eastern oyster has an overall pH tolerance of 6-9, which was a broader tolerance then I initially expected. This could suggest that the eastern oyster is capable of regional adaptations to low pH (Clements et al, 2020). The future of pH within the Chesapeake Bay is predicted to decrease if climatic and environmental stressors continue (Cai et al., 2017). Specifically, a pH minimum zone has already been detected within the Bay and is continuing to become more acidic (Cai et al., 2017). However, the Bay seems to be performing a buffer process to prevent the deeper waters from becoming acidic by dissolving the shells of living and non-living organisms (Cai et al., 2017).

One possible limitation within my research would be the area of the Bay that the monitoring stations used covered. Due to the lack of monitoring stations available in the southern most regions of the Chesapeake Bay, I could not complete a full analyzation of optimal areas for eastern oyster suitability within the Bay. An additional limitation to my research is that since the values for the variables used were averaged from 2019-2021, this does not show the seasonal variability of these characteristics. Additionally, by utilizing the average values of these variables the current values of the Bay are not being considered.

Overall, the results of my habitat suitability index indicate that the optimal region of the northern part of the Chesapeake Bay for eastern oysters is found between Annapolis and St. Leonard. These findings could be useful in a number of ways. Specifically, this area could be utilized for future oyster reef building, eastern oyster conservation, and commercial oyster harvesting. Future similar studies should be conducted in order to continue to monitor the characteristics of the Chesapeake Bay and how these characteristics impact vital species like the eastern oyster.

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